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Thesis

METHODS OF COMBATING PATHOGENIC ORGANISMS IN THE AIR

by

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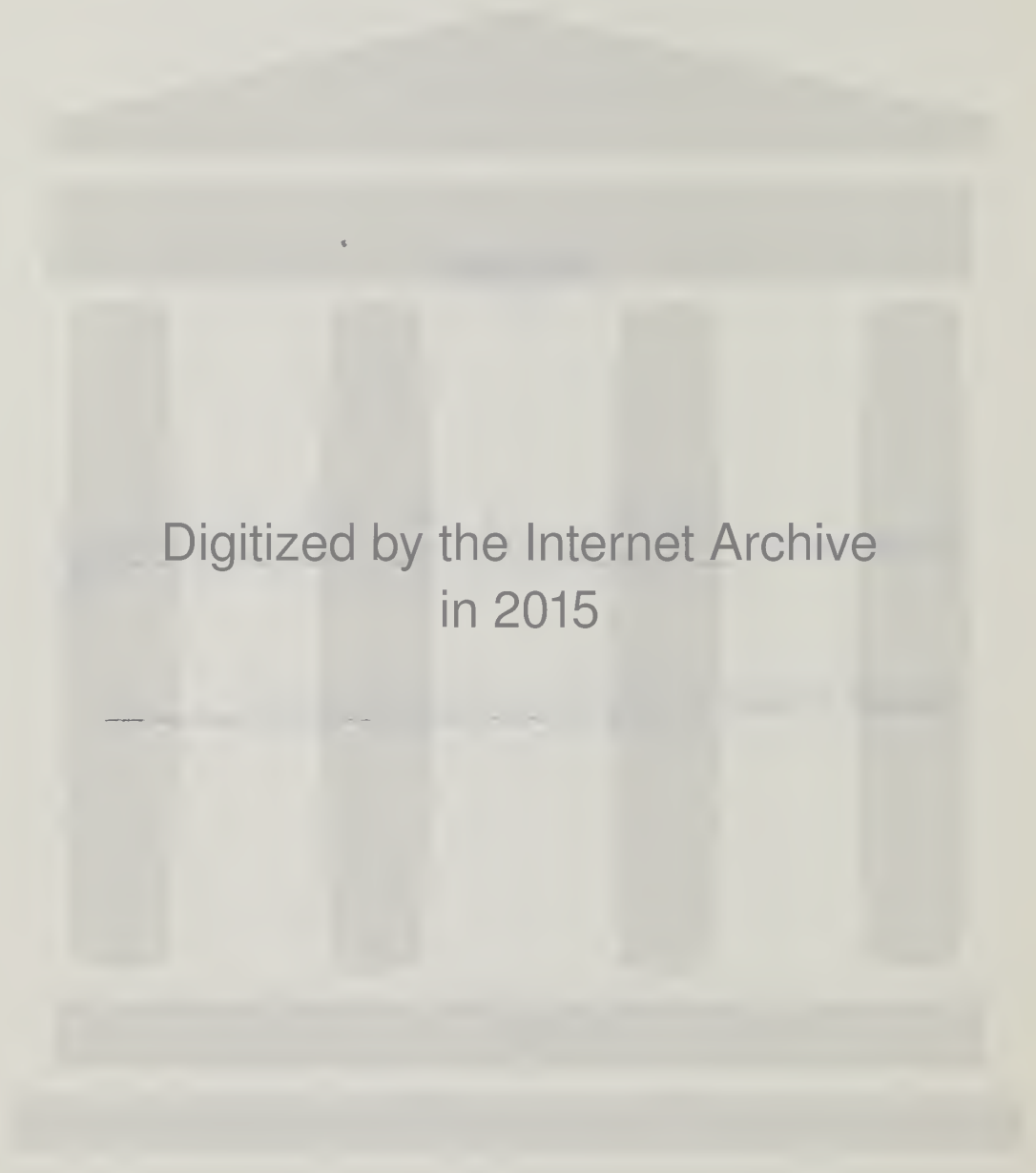
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Introduction

Respiratory infections constitute a major public health problem in the Temperate Zone. The combined death rate from the various respiratory infections is second only to heart disease; while the ubiquitous common cold is a notorious offender, not only in its own right but as a trail blazer for more insidious organisms.

Intestinal diseases have been eliminated by pure food and water. Perhaps it is not unreasonable to hope that purification of the air supply wherever people congregate, will eventually eliminate respiratory infections.

Dust, Droplets, and Droplet Nuclei

Evidence is rapidly accumulating to indicate that the air is an important intermediary in the spread of bacterial and viral infections. Wherever people congregate they contribute microörganisms into the air, in talking, coughing, and sneezing. The larger particles influenced by gravity fall to the floor, while the smaller droplet nuclei may float around, wafted about by air currents, until removed by ventilation, disinfection, or inspiration.

According to Wells, Winslow, and Robertson (55) pathogenic organisms may be present in the air in the form of dust, droplets, and droplet nuclei. They differentiate the forms as to size and consequent settling velocity. Dust arises as a result of attrition, falls at the rate of a foot per minute to a foot per second, is 10 to 100 microns in size. Droplets represent spray from the nose or throat, settle at a velocity greater than a foot per second, are more than 100 microns in size. Residues of droplets after dessication give rise to infected dust particles which may be lifted into the air again during room activity. Droplet nuclei are the residues of small droplets which have evaporated, are two to ten microns in size with a settling velocity of less than a foot per minute. Wells (45) has observed that most droplets evaporate before falling the height of a man. Henderson (communication to Rosebury 35) indicates

that droplets as large as 20 microns in diameter evaporate very rapidly with relative humidities as high as 75%.

The state of suspension of microörganisms in the air is an important factor in determining methods of combating them. It is self evident that minute droplet nuclei floating in the air would be susceptible to a different treatment from the larger dust particles on the floor. Moreover, the relative hygienic significance of each state of suspension should be an important consideration in practical applications.

In an experiment at the Harvard School of Public Health, (51) E. coli cultures were added to the humidifying system of one basement room equipped with air conditioning. E. coli was recovered not only from the air of that room, but within two hours was recovered from all parts of the building, first, second, and third floors. Suspended in the form of droplet nuclei, the organisms were distributed by air currents throughout the building.

Since droplet nuclei may remain suspended in the air for considerable periods of time because of slow settling rate, the viability of the microörganisms which may be associated with them is an important factor in spread of infections. Wells and Wells (53) report that pneumococcus type I, C. diphtheriae, S. hemolyticus, S. viridans, were recovered after two days. Intestinal organisms, E. coli, S. typhosa, S. paratyphi, were recovered at the end of eight

hours. They observed that apparently these organisms of the respiratory tract were more viable than the intestinal organisms.

Del Mundo and McKhann (6) report the recovery from the air using a centrifuge, of Hāemophilus influenzāe type B. This pathogen was present for two days following the removal of two fatal cases from the ward. This same organism had been isolated in material from the nasopharynx, ears, and spinal fluid of those cases.

The relative hygienic significance of droplets and droplet nuclei and dust, may be determined by their size and their corresponding place of deposition in the respiratory tract. Hatch (16) states that particles larger than five microns are removed in the upper part of the tract. Infectious material, according to this author cannot reach the alveoli unless the particles are sufficiently small. Accordingly, he feels that dust and droplet infection is therefore limited to the upper respiratory tract, while droplet nuclei, consisting of one organism or a very small group of organisms, penetrate to the alveoli. This has been substantiated by Wells and Ratcliffe (50). Rabbits exposed, by inhalation, to large particles of tubercle bacilli settling a foot per minute, developed fewer, by far, tubercles in the lung than other rabbits exposed to the same number of organisms in the form of smaller nuclei, settling at the rate of less than a

tenth of a foot per minute. These observors feel that hygienically the small nuclei, expelled in coughing, sneezing, and talking, are potentially capable of greater pulmonary damage than the larger, coarser droplets, and bacteria-bearing dust particles. In experiments conducted with fine droplet nuclei of single organisms (50), tubercle bacilli were deposited almost quantitatively in the alveoli, each organism apparently giving rise to a tubercle. This was not true of coarse particles. Fewer than 10% of nuclei settling more than a foot per minute reached the alveoli.

Jennison (19) has taken high speed photographs of droplets expelled during coughing, sneezing, and talking. The average sneeze seems to result in the expulsion of about 20,000 particles, although some sneezes have been photographed with as many as 40,000 expelled particles. From calculations of the size of the particles Jennison has found that within a fraction of a second most of them have evaporated. Pronunciation of the consonants, particularly "f", "p", "t", and "s" is quite productive. Loud talking is comparable with sneezing in expulsion of droplet nuclei.

That microorganisms are actually projected into the air in sneezing has been demonstrated by Wells and Wells (53). After successfully dispersing sneeze powder into a classroom of students, they collected thousands of alpha streptococci in air samples.

Experimentally, animals have been infected by inhalation of air containing influenza A virus (49), pneumococcus type I (49), M. tuberculosis (24), M. mallei (35), M. pseudomallei (35), B. suis (35), P. tularensis (35), the three strains of psittacosis virus (35), and meningopneumonitis virus (35).

Studies of measles (42), mumps (42), and chickenpox (9, 42), indicate spread by means of droplet nuclei. The Commission on Acute Respiratory Diseases (4) considers atypical pneumonia to be air-borne. Lurie (24) has shown that normal guinea pigs in the same room with tuberculous animals acquire tuberculosis of respiratory origin even though the cages are placed at considerable distances from each other. He found that the types of tuberculosis acquired by animals of low genetic resistance and resistant animals correspond closely to the types of tuberculosis seen in man.

Dust has been implicated in the cross infections of the nose and throat particularly with hemolytic streptococci. Since most attacks of acute rheumatic fever are associated with a previous history of streptococcal infections (56), an increased knowledge of the epidemiology of these organisms would represent an advance in our understanding of rheumatic fever.

Beyond the brief indication that pathogenic organisms

can be projected into the air during respiratory processes, as nuclei may float about as a potential hygienic hazard to other occupants of enclosed areas, or as larger droplets may settle upon the floor contaminating the dust, it is not the purpose of this paper to dwell further on the state of suspension of these organisms, but to proceed to a survey of air bactericides.

Physical Barriers

In recent literature various methods have been suggested for combating pathogenic organisms in the air. Physical barriers such as cubicles in infants' hospitals, and masks have been an accepted practice for many years.

Rosenstern (37), and Sauer et al (38) have described barrier units set up in The Cradle. With the Dick's aseptic technic they previously eliminated infantile impetigo and enteritis, but respiratory cross-infections remained a problem. Three types of experimental units were set up, (1) a unit with 12 cubicles air conditioned with fresh outside air every six minutes; (2) 12 cubicles with ultraviolet light barriers which will be mentioned again when irradiation is considered; and (3) 6 cubicles subdivided by sliding glass partitions into two sections, an inner or infants' section, and an outer or nurses' section each with its own air supply. A greater air pressure is maintained in the infants' section, so that when a partition is raised to attend to the infant, air flows into the nurses' section. Clinical observations on the incidence of infections of the respiratory tract were as follows: out of 17 cases of respiratory cross-infection, 15 occurred in the control or air conditioned cubicle while only one occurred in the barrier unit.

The principle underlying the use of mechanical barriers is isolation (30). Ideally if everyone has his own individ-

ual and private air supply no cross-infection would occur. Reyniers and Trexler (31) also suggest the use of spot ventilation i.e. simple mechanical filters attached to the ceiling through which air was constantly being forced. No bacteriologic evidence as to the efficiency of these filters is offered. They do state that such spot ventilators are more efficient against dust than droplet nuclei.

Reyniers (30) has developed a germ-free system wherein animals may be maintained in an absolutely sterile atmosphere by passing the air supply taken from the outside through three glass type fiber filters, and then sending it through 30 inches of glass wool. In tests, E. coli nuclei were removed from air by forcing the air through a one-foot-long, dry, glass wool filter.

From personal observations of the Reyniers' unit at The Chicago Cradle, it seems rather awkward for the nurse to attend to the infants. The sliding partition which separates nurse and infant can not be raised above shoulder level. Moreover, there is the problem of whether the child can be heard crying or coughing through two glass barriers.

If these difficulties can be ignored, the barrier cubicle is a means of eliminating cross-infections in infants' wards.

The Chapple incubator for premature infants at the Children's Hospital of Philadelphia is an air tight chamber,

with the air supplied from outside. The outside air is however first dehumidified, then humidified again to the desired level, and heated to the proper temperature. No respiratory infection has been observed in 500 premature infants, while in a control group the mortality from respiratory tract infections was 40%.

An individual air supply with the use of mechanical barriers is an effective means of preventing cross-infections in premature and very young infants. However, for general application for all age groups, in theatres, schools, etc., wherever people congregate, other methods of eliminating pathogens appear more practicable. The situation seems analogous to boiling everyone's individual milk supply, when pasteurization, which while not removing all bacteria, suffices to prevent the spread of disease.

Masks, as a bacterial barrier have not been effective in the prevention of wound infection in operating rooms (15). Van den Ende (40) admits they are ineffective as a barrier for droplet nuclei. Del Mundo and McKhann found masks did not prevent secondary infections, although they did diminish some transmission of organisms (6). Jennison's high speed photography (19) shows fine droplets projected through masks by sneezing. With less permeable masks, droplets are forced out under the edges of the mask. The interesting observation is made (19) that finer particles seem to result

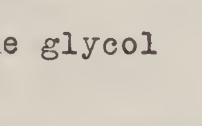
in sneezing with more permeable masks perhaps due to the breaking up of the larger droplets by the thread or meshwork of the mask. Therefore, the value of the mask as a barrier for droplets and droplet nuclei is questionable.

Aërosols

In order to be a satisfactory germicide in vapor form a substance must have certain characteristics: (1) it must be non-toxic to human beings and animals in the maximum amounts to be inhaled; (2) it must be inexpensive; (3) it must be tasteless and odorless; (4) it must have marked germicidal action; (5) it must not be corrosive or injurious to room surfaces, whether paper, wood, fabric, leather, or metal. Several substances which were found to be highly germicidal did not satisfactorily meet the other criteria. Sodium hypochlorite (NaOCl), for example, although germicidal in extremely low concentrations, was found to possess an odor and was corrosive to metals. Hexylresorcinol also highly germicidal was too expensive to be used on a large scale.

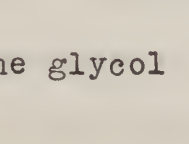
The chemicals which do meet the specifications for the ideal air-sterilizing compound were found to be the glycols, ethylene, propylene, and triethylene. Glycols are dihydroxy derivatives of the paraffins, discovered by Wurtz in 1856. They form a homologous series of the general formula $C_nH_{2n}(OH)_2$

Ethylene glycol



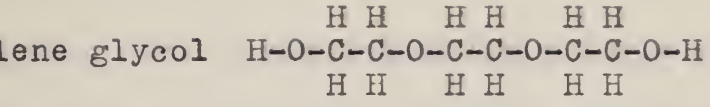
the simplest stable glycol

Propylene glycol



1,2, propylene glycol

Triethylene glycol



1,6, triethylene glycol

Although all three compounds are very similar, thick, hygroscopic, neutral liquids, they differ in some respects. Of the three, propylene and triethylene glycol are the most satisfactory aërial bactericides. Triethylene glycol is over 100 times more effective than propylene glycol in air, yet less effective in vitro. All the glycols require extremely high concentrations to have any bactericidal effect in vitro. Propylene will not produce death of Staphylococcus albus until a concentration of 70% has been reached in vitro (26, 27). Yet it produces extensive killing of air-borne organisms at concentrations far below the saturation point. In an experimental chamber (32), a gram of the compound in 71 to 141 cubic feet of air produced almost instantaneous death of various kinds of bacteria, such as, pneumococci, hemolytic and non-hemolytic streptococci, S. aureus, S. albus, H. influenzae, H. pertussis, E. coli, M. catarrhalis, and B. subtilis. Robertson notes (32), that the pathogens seemed more susceptible to the glycols than the non-pathogens.

The efficacy of the glycols as aërial bactericides is intimately associated with the relative humidity. They are most effective at relative humidities between 40 and 60 per cent. If the relative humidity rises above or falls below

these figures, the bactericidal efficiency falls rapidly. Thus at relative humidities of 15% and 80%, the glycols exhibit no appreciable germicidal power.

Puck (26, 27) finds that the germicidal action of the glycols occurs during the vapor phase, and not in the aërosol or fine mist phase. The killing action is not due to the collision of germicidal molecules and air-borne bacteria but due to the condensation of glycol molecules in vapor state onto the bacteria-containing droplets. He comments that at low humidities the germicide may become completely ineffective, and may even resist condensation on dried particles. The glycol particles condensing on the moist bacteria-containing particles at favorable humidities raise the concentration of glycol up to lethal values (70 to 80%). At any relative humidity the killing action is greater the more closely the vapor approaches the saturation point. The saturation concentration of the germicidal vapor in the air is determined by the relative humidity, thus at 0 relative humidity the air contains germicidal vapor equal to the vapor pressure of the pure compound, and conversely, at 100% relative humidity there is no glycol in the air in vapor state. Therefore a high relative humidity precludes the presence of a high concentration of glycol vapor in the air. This condition, therefore, accounts for the low germicidal efficiency of glycol vapors at high relative humidities.

Wise and Puck (58) in studies on saturation concentrations of triethylene glycol, have found that the relative saturation of the air with glycol is not only a function of the relative humidity but also a function of the temperature. Raising the temperature increases the capacity of the air to hold triethylene glycol vapor, if the relative humidity is maintained at the same level.

The investigations of Hamburger et al (13) however, seem to indicate that low temperatures increase the efficiency of glycol vapors and high temperatures decrease their efficiency, i.e. bactericidal action is greater below 72 F than above this point.

Triethylene glycol, much more efficient as an air bactericide than propylene glycol, has the additional advantage of a decreased tendency to condense on cold surfaces.

The previously cited experiments with glycols were made upon bacteria in fine droplet nuclei form. Robertson and associates (32) using beta hemolytic streptococci isolated from the air of scarletinal wards, sprayed large droplets of culture into a room. These droplets settled to the floor. After 17 to 24 hours, time permitted for dessication, the floor was swept, steam was introduced, and 40 minutes allowed for hydration of the dried bacteria. Triethylene glycol then yielded sterile samples of air. However, when the relative humidity was maintained at 24%, triethylene

glycol was not effective. There was no appreciable kill. They concluded that triethylene glycol was not effective against dessicated bacteria.

Saturation Concentration of Triethylene Glycol Vapor as a Function of the Relative Humidity*

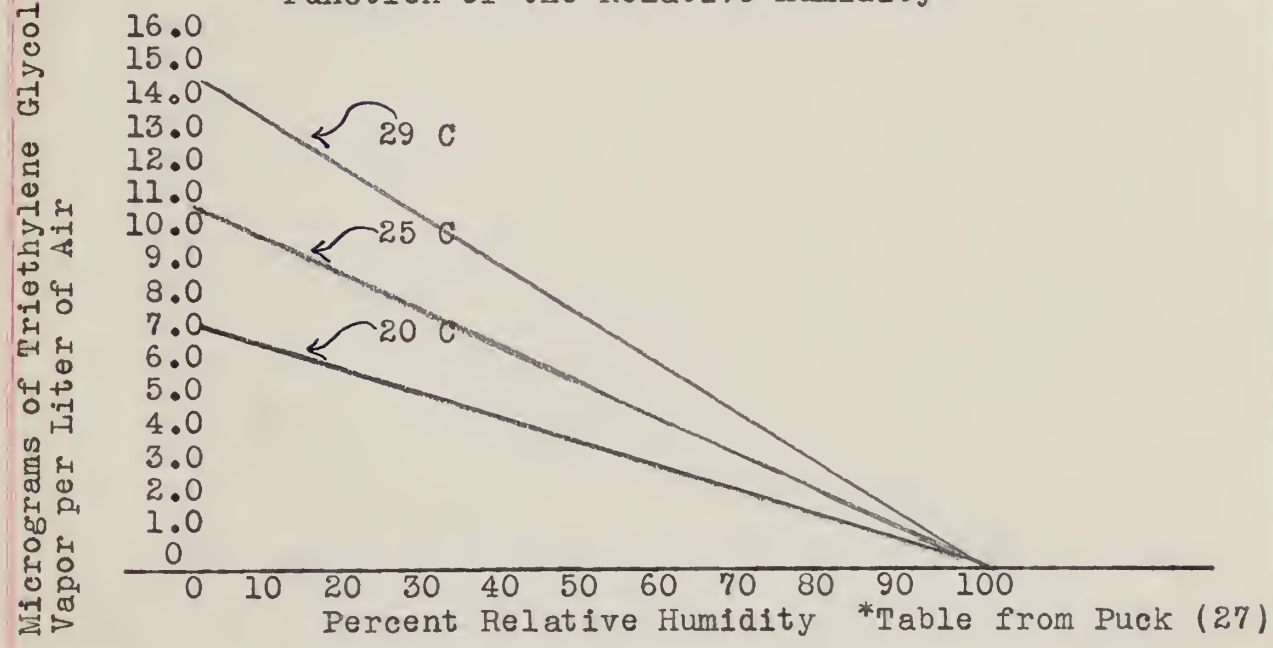


*Table from Puck (27)

A few practical applications of bactericidal sprays may be cited here. Harris and Stokes (14) in a study for over a period of three years on the incidence of respiratory infections in a convalescent home for children, used propylene glycol for two years and triethylene glycol for one. The beds of the children were sufficiently separated to eliminate infection from droplets. The children were confined to bed. The concentration of propylene glycol was maintained at 0.069 mg. per liter, and triethylene glycol at 0.0018 to

0.0033 mg per liter. Relative humidity was maintained between 30-40%. They found the rate of incidence of respiratory infections (coryza, tracheobronchitis, nasopharyngitis, and otitis media) markedly lower in wards containing glycol vapor than in control wards.

Epidemiologic observations (1) of the effect of triethylene glycol vapor together with oiling of floors and bedding in sleeping quarters of 1000 men, with 1000 others as controls, resulted in a reduced incidence of hemolytic streptococci in throats. Air sampling conducted in sleeping quarters with the glycol vapor showed an overall reduction in bacterial count and practical abolition of hemolytic streptococci. The incidence of mumps was reduced in the group sleeping in the glycol treated atmosphere.

In no case has inhalation of glycols given evidence of irritation of the respiratory tract. The main problem with glycol vaporization is to keep the solution below 260 F which is the disintegration point of glycols, as nothing is known of the toxicity of the resulting products.

Another problem with glycol vapors is the matter of raising the relative humidity in the winter time when indoor heating is apt to reduce the humidity. The concentration of the glycol must be kept just below the saturation point. If it is kept much lower, the bactericidal efficiency is

diminished, if higher, it will condense on cold surfaces in the room. Some type of regulating device or glycostat should therefore be used for practical applications.

Two English observors (25), reporting on the effect of a hypochlorite spray used in military barracks with an ordinary Flit type gun sprayer, noticed a reduction in the incidence of respiratory infections.

Lovelock (23) has found many organic compounds effective in destroying the organisms of sprayed saliva (S. salivarious and others). The homologous series of aliphatic alpha-hydroxy carboxylic acids (glycollic, lactic acid, etc.) and the mono esters of maleic acid and two mono esters of succinic acid can be used as aerial disinfectants. Lactic acid has been used by many observors, but Lovelock (23) reports that compounds of the straight chain series type $H_3C-CH(OH)-COOH$ (lactic acid) have a tendency to decompose.

It is highly probable that future experimentation will lead to more satisfactory aërial bactericides than the glycols. The very short range of relative humidity 40-60% which permits maximum germicidal activity of the glycols is a decided handicap in practical applications.

Treatment of Floors and Bedding with Oil

Loosli and Robertson (21) report that the diphtheric and tubercle bacilli, pneumococci, and staphylococci have been isolated from ward dust. Many observors report hemolytic streptococci in dust (39). Since ultraviolet light and glycol vapors are limited in their action against dust-borne bacteria, control of dust and lint in bedclothing and floors has received considerable attention.

United States Government specifications for floor oils require that they should have a flash point of 300 F or higher, and a pour point not higher than 30 F, and should be clear petroleum oils, well refined, free from sediment and foreign material, with no objectionable odor.

Loosli and Robertson (21) suggest one gallon of oil per 1000 sq. feet on a wooden floor, to be repeated every two or three weeks. Unfinished wooden floors may take as much as one gallon per 150 sq. feet. This heavy application lasts for six months. Smooth floors of composition linoleum, or varnished and waxed wooden floors require smaller doses at more frequent intervals. Robertson and others (33) recommend a compound consisting of urea 5%, ninol (a synthetic detergent) and roccal (the commercial form of Zephiran), 3% ninol and 0.1% roccal. This however must be reapplied frequently.

Thomas (39) reports finding Streptococcus pyogenes repeatedly in samples from the air, bedclothes, and dust

of wards where tonsillitis exists. Thomas by the use of spindle oil applications on an unpolished wooden floor in hospital wards was able to reduce by 80% the number of organisms raised into the air by sweeping.

In order to eliminate the dust liberated from bedclothes during bedmaking procedures, oiling of blankets has been used with success. Van den Ende and Thomas in England (41) have used medicinal liquid paraffin in a light petroleum solvent. However, due to fire hazard and the scarcity of this material during the war, a highly refined inert mineral oil was used. Spindle oil, which has been used in the oiling of floors, because of its carcinogenic properties is unsuitable for blankets which have intimate contact with the skin.

Mineral oil emulsion in a 20% water solution in the final rinse water was found satisfactory for blankets and bedclothes (41). It was noted that the oiled blankets exerted a bactericidal effect upon bacteria landing on the blanket in a wet state from droplets. This bactericidal action is not so pronounced with bacteria in the dry state. Van den Ende and Thomas (41) ascribed the bactericidal action of the blankets to the emulsifying agents used in preparing the oil. The dust laying properties of the oiled blankets were however, mainly responsible for the reduction in the amount of bacteria in the air. In actual hospital trials they

found that the number of organisms liberated by bedmaking were reduced 99% with oiled bedding. Puck and others (28) have duplicated the British results with a 95% reduction in liberated dust from blankets that have been oiled, and a reduction of 91% and 97% in streptococci liberated from oiled blankets.

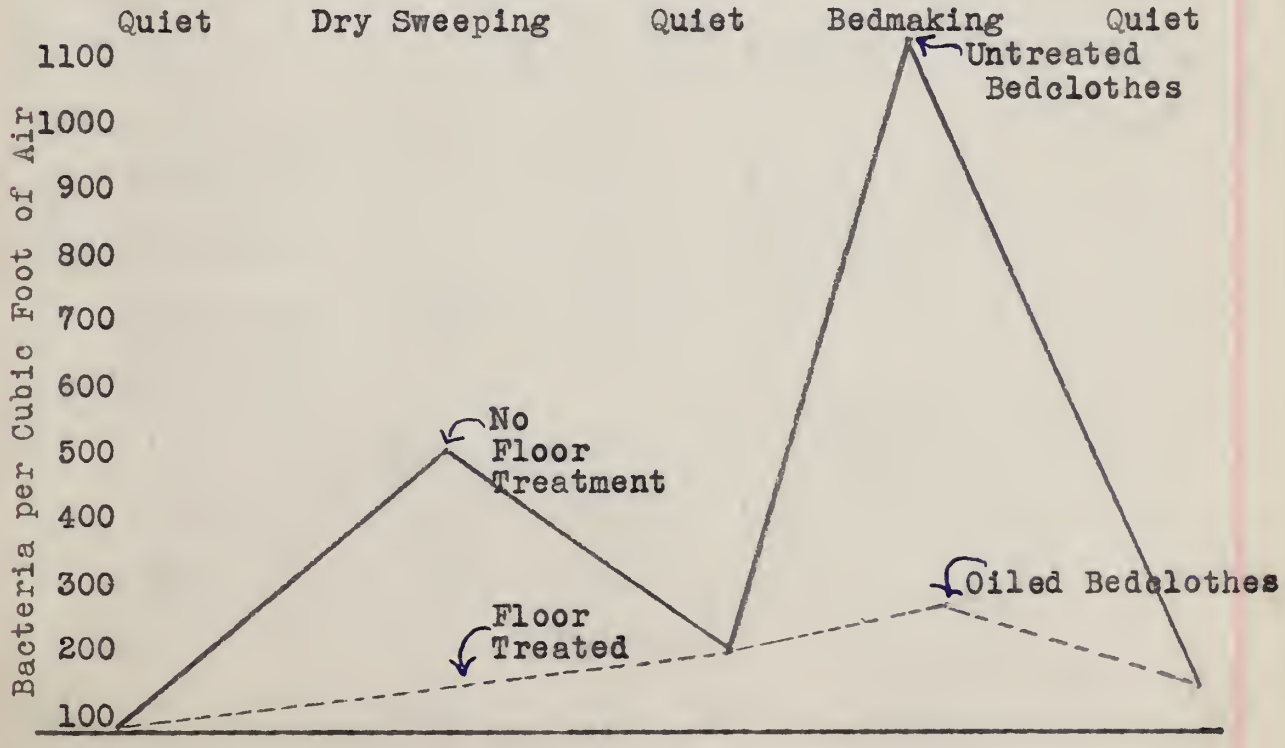
Blankets dipped in germicides they found (28) were not effective against dried bacteria, partially against organisms deposited in a moist state.

American investigators (28) found Triton NE (30% water solution of a substituted phenyl ether of polyethylene glycol) a most satisfactory emulsifier when used with mineral oil (Fractol A). Blankets treated with this combination could not be distinguished from untreated ones in appearance or texture. Loosli and others (22) have worked out a practical laundry technic for the use of Triton and oil emulsions. After an initial heavy treatment, small amounts of the emulsion on subsequent washings will be sufficient to maintain optimal dust retaining qualities. Oiling of floors lengthens the period of dust retention in treated bedclothes.

Robertson (33) has found that sweeping and bedmaking dispersed hemolytic streptococci into the air. The use of triethylene glycol alone resulted in 70% reduction in the number of air-borne streptococci, and with floors and bedding oiled 90% reduction.

Hamburger et al (12) report finding hemolytic streptococci in air samples taken in scarletinal wards. The authors raise the question as to whether these are droplet nuclei or organisms dispersed from bedding and floors. They conclude that the majority are raised by activity and relatively few are present as droplet nuclei. They report that cultures of pajamas, sheets, pillowcases, and blankets have repeatedly shown hundreds or thousands of hemolytic streptococci. Thus the control of air-borne streptococci in hospital wards may be largely a question of control of the secondary reservoirs in dust and bed linen.

Reduction in Bacterial Content of Ward Air by Floor Treatment and Use of Oiled Bedclothes
(Taken from Robertson et al 33)



A practical test of the effect of oiling both bedding and floors upon incidence of respiratory infections in new recruits at Fort Bragg, N.C., was carried out by the Commission on Acute Respiratory Diseases and the Commission on Air-Borne Infections (5). Floors were oiled with a petroleum-distillate floor oil. Bedding was treated with an emulsion of 87 parts mineral oil and 13 parts Triton NE. Four barracks of 240 trainees each were used for the test, two as a control, and the other two subjected to the complete oiling treatment of floors and bedding. Of the respiratory infections 90% were acute respiratory disease. Oiling of the floors and bedclothes did not make any appreciable difference in the incidence of this infection. There was a 75 to 90% reduction in bacterial counts where oiling procedures were practiced and an almost complete absence of dust. The authors state that perhaps the failure of the oiling procedure in reducing the incidence of acute respiratory diseases is that these diseases are "transmitted through direct contact, or through droplet nuclei, rather than contaminated dust".

Irradiation with Ultraviolet Light

The bactericidal range of ultraviolet light is between 2000 and 3000 Angstrom units of the resonance band of mercury with the most efficient band commonly considered as at 2537 Angstrom units. For practical applications the lights are primarily of two types, cold quartz and high transmission glass. The low pressure quartz light emits 93 to 95% of its ultraviolet radiation between 2500 and 2600 Angstrom units. The special high transmission glass General Electric light has a transmittance of 80% at 2537 Angstrom units, and 1% at 1850 Å. The Westinghouse light has over 85% of its output at 2537 Å. Both lights have proved to be efficient in installations.

Since eyes are sensitive to the light precautions must be taken in set ups to prevent irritation of the conjunctiva where prolonged exposure to direct irradiation is possible. In practical experience, however, this does not appear to be a serious problem. There is not much danger of erythema as the bactericidal wavelength is shorter than the erythemal which is at about 3000 Å.

There are several factors which govern the efficiency of ultraviolet lights upon microörganisms. Bacteria growing in groups or clusters are more resistant to this light than organisms which seem to be in the form of individual cells as E. coli, or along one plane as the streptococci according

to Wells and Wells (53). These investigators found that staphylococci, sarcinae, and spores were more resistant than E. coli. For this reason it seems that dust, which is composed of groups of organisms is more resistant to irradiation than droplet nuclei, which are individual organisms. Influenza virus qas shown to be effectively destroyed (99%) by ultraviolet light (49). Chickenpox (9, 42), measles and mumps (42) have also been adjudged vulnerable, an indication that viruses are as vulnerable as individual bacteria.

Relative humidity is another factor governing the efficiency of ultraviolet radiation. Wells (46) has shown that at lower relative humidities the light is more efficient than at higher humidities. At a relative humidity of 46% the efficiency is ten times that at 91% relative humidity. Fortunately, the time of greatest need for irradiation for sanitary ventilation occurs during the season when windows are closed and indoor heating lowers the relative humidity. Thus droplet nuclei are particularly vulnerable.

Therefore if we assume, and there is evidence to support the assumption (50) that droplet nuclei are of great hygienic significance in transmitting respiratory infections, ultraviolet radiation may be considered an extraordinarily well suited air germicide.

Practical applications of the germicidal properties of ultraviolet lights are for the most part the result of the

work of W.F.Wells, who has devised various types of installations particularly adapted to the needs of the area to be irradiated.

A. Irradiation of Recirculated Air

Irradiation of recirculated air has been in use for many years in railroad cars, the ultraviolet light being installed as an intrinsic part of the air conditioning system (45). The efficacy of this type of installation is determined by the rapidity of recirculation of the air in the car. With the recirculation of irradiated air, the microörganisms in the car are diluted to the same extent as they would be with the addition of an equal volume of fresh outdoor air. A test of the efficiency of this type of installation in a model coach at B.F. Sturtevant Co., Hyde Park, Mass., is included at the end of this paper.

B. Direct Irradiation of Room Air

The direct type of irradiation has been used in operating rooms. Beams of light are focussed upon the operating table. This strong irradiation is necessary to destroy the larger particles of bacteria which may settle out onto the exposed surface. Simple eyeglasses give adequate protection to the operating room personnel.

Hart (15) reported that despite scrupulous aseptic technic, many of which he called "unexplained infections", usually hemolytic Staphylococcus aureus, occurred in clean wounds.

During a period of five and a half years after the installation of ultraviolet light irradiation, infection rate was reduced to a small fraction of the previous level and no death has resulted from infection. Previous to irradiation there were 19 deaths from infection in 1782 major clean operations; with irradiation there were no deaths in 2600 similar operations.

Two tests on the bactericidal efficiency of this type of installation made at the Deaconess and Cory Hill hospitals, Boston, Mass., are included at the end of this paper.

C. Partial Irradiation of Room Air

In classrooms and institutions where direct irradiation of the air may not be practicable because of constant occupancy, indirect or partial irradiation has proved satisfactory. M.W.Wells (42) studied the effect of installation of lights in public schools in the vicinity of Philadelphia, Pennsylvania, on the incidence of measles, chickenpox, and mumps. The lights which irradiate the upper half of the room were in the form of a central hanging fixture in one school, and as a sidewall fixture in another. She found that the chances of transmitting these childhood diseases were considerably diminished in irradiated rooms. The standard school ventilation was inadequate to prevent the spread of virus infections. Irradiation of the upper air in the classrooms, by diluting room air, effected a definite reduction in

the transmission of the three diseases.

It has been possible to test the efficiency of such installations and translate such efficiency into the number of turnovers or air changes per hour with the use of a technic developed by W.F.Wells. E. coli, a harmless organism, is atomized into the air. By taking air samples with the Wells centrifuge the rate of removal of the test organism without ultraviolet lights can be calculated and compared, with the rate of removal of the organism with ultraviolet irradiation.

During cold weather when economy limits ventilation to about 10 to 20 air changes per hour because of closed windows (54), infections are easily transmitted among occupants of enclosed areas. With indirect irradiation, 100 air changes per hour are easily attained. This tenfold increase in ventilation has, according to Wells (45),

> "checked the dynamic classroom spread of childhood contagion during the winter in one school for seven years and in two other schools for four years. Meanwhile these ancient diseases have pursued their familiar course in adjoining schools."

Indirect irradiation with two ultraviolet lights in an infants' ward gave dramatic evidence of the efficiency of the lights (9). In a non-irradiated ward every child was infected with varicella, while in an adjoining irradiated ward, children sharing the services of the same night nurse, escaped the disease. These observors also reported a 50%

reduction in respiratory infections in the irradiated ward, and with an improved set up considered that even better results could be secured.

D. Light Barriers

Ultraviolet light has been used as a bactericidal wall to prevent cross-infections in children's hospitals.

Twelve cubicles designed by W.F.Wells using ultraviolet light as a barrier were installed in the Evanston, Illinois, Cradle. All twelve have ultraviolet lights placed over the entrance to each cubicle. Six have solid partitions separating them. Six others have alternating partitions removed and replaced with additional ultraviolet lights. Bacterial tests at The Cradle with E. coli, showed these lights to be extremely efficient in destroying practically all of the organisms in transit, both from the cubicles into the hall and from the hall into the cubicles.

Rosenstern (37) in a report on observations on respiratory cross-infections in the cubicles for a period of two years, disclosed that only one respiratory cross-infection occurred in the light cubicles, while 15 occurred in the control unit.

Del Mundo and McKhann (6) in a survey of the records of the Infants' Hospital, Boston, showed that 12.5% of patients admitted over a two-year period contracted infections in the hospital. Two ultraviolet lights of high transmission

glass with aluminum reflectors based on the design of W.F. Wells for The Cradle were placed over the entrance of each cubicle. The total bacterial counts were brought down well below half of the original counts. In the control wards 12.5% of the children developed infections over one half of which were respiratory in origin. Only four new infections developed in the irradiated ward, a rate of 2.7%.

To complete this survey some mention must be made of some large scale irradiation projects. During the war, ultraviolet light irradiation of the sleeping quarters of various military training centers (57, 18, 20) and the sleeping quarters in a boys' training school (7) was observed. The results, while showing a somewhat reduced rate of respiratory infections in groups sleeping in irradiated atmospheres, were not conclusive. Apparently irradiation of only one place of congregation of a group is not adequate. In the above instances, mess halls, drill centers, corridors, etc., were not irradiated and apparently sufficient infections were transmitted by congfegation in the unirradiated atmospheres to prevent clear cut differences in the irradiated and control groups.

Wells (45) maintains that irradiation of one atmosphere does not afford adequate protection, only when irradiation becomes a general procedure and people can be protected

in all atmospheres will significant results be obtained.

The Effect of Ultraviolet Radiation upon Bacteria in Air*

The purpose of this series of experiments was to determine the bactericidal efficiency of various ultraviolet light installations. Two types of installations in use at the present time were tested; operating room installations at the Deaconess and Cory Hill Hospitals, and railroad car installations in the model coach constructed by the B.F. Sturtevant Company of Hyde Park, Mass.

The test organism for these experiments was Escherichia coli. Cultures were atomized into the air in 5% dilutions by means of a humidifier of the type manufactured by the Gas Accumulator Company. This instrument insured uniform contamination of the atmosphere when used in combination with an electric fan or blower. Samples of the air were taken by means of the Wells Air Centrifuge, which provided a quantitative method for the determination of the number of viable organisms in the air. Glass cylinders containing about 25 c.c. hot agar (in this case, Levin's Eosin Methylene Blue) were inserted into the machine. A central axial tube lead directly into the center of this cylinder from the outside. When the platform bearing the tube revolved, air was sucked into the tube and the nutrient agar rose and solidified on the inner surface of the tube. Simultaneously organisms were precipitated upon the surface of the agar. The glass tubes or cylinders were then incubated for

*Research problem, Boston University Graduate School

18 to 24 hours, or overnight. After incubation, the colonies were counted, tubes containing less than 200 colonies by hand and those containing more than this number by means of a microscope.

A Venturi nozzle fitted over the outer end of the central axial tube was calibrated for one cubic foot per minute. Since the tubes in the following experiments were five minute samples, they represented five cubic feet of air in the area sampled.

Due to the distinctly different types of installations in the railroad car and in the operating room, irradiation of recirculated air in the former and direct irradiation in the latter, different set ups were used for the experimentation.

In the railroad car, the air-conditioning duct which runs along the ceiling of the car was used to distribute the organisms throughout the car. Another duct containing the ultraviolet lights to be tested was horizontally located running along the center of the car about one foot from the floor. The lights were placed in the intake of this duct. Two simultaneous samples of air were taken, one before the air reached the lights and another sample of the effluent coming out of the light duct, after passing the light. Comparison of these two samples could thus be calculated on a percentage basis and an estimation of the efficiency of the

lights used determined.

Tables I, II, III, represent such tests in the railroad car, Table I of 3 thirty inch Westinghouse lights, Table II of three jacketed Hanovia cold quartz lights, Table III of six ten inch hot cathode Westinghouse lights.

In the operating room an electric fan was used to disseminate the E. coli. The atomizer was placed in one corner while samples of air were taken directly at the operating site. The ultraviolet lights in aluminum reflectors were installed about ten feet from the floor on the wall of the room and were directed upon the operating room table. At the Deaconess Hospital four cold quartz lights were used each about 16 inches long and at the Cory Hill Hospital one 20 inch cold quartz light.

Table IV records the Deaconess Hospital run, Table V, the Cory Hill Hospital run.

Table I

Sturtevant Run
E. coli dilution of 27 hour culture
Three thirty inch Westinghouse lights used
Odd numbered tubes before the light
Even numbered tubes after the light
Atomizer on 1:42 P.M. on during the whole run

Tube No.	Time	Lights	Relative Humidity	Log. Count	Actual Count	Kill
I	2:23-38	on	47.0%	3.2582	1811	82.1%
II				2.5122	325	
III	2:29-34	on	47.5%	3.0985	1255	64.8%
IV				2.6499	442	
V	2:35-40	on		3.1143	1301	92.9%
VI				1.9682	93	
VII	2:42-47	on	46.5%	3.0382	1092	86.7%
VIII				2.1614	145	
IX	2:48-53	on	46.0%	3.0563	1139	83.7%
X				2.2695	186	
XI	2:54-59	on		2.8712	743	86.4%
XII				2.0043	101	
XIII	3:00-05	on	46.0%	2.9343	860	77.0%
XIV				2.2967	198	
XV	3:06-11	off		2.9459	883	
XVI				2.8575	720	
XVII	3:13-18	off		2.8712	743	
XVIII				2.9682	929	

The average percent kill is 85.3%. Tubes I,II,III, and IV, were not considered in the average. The manometer nozzle on the centrifuge was found open about two minutes after Tubes I and II had started spinning. The percent of kill calculated from Tubes III and IV is very much out of line with the results of the other tube counts. Tubes XV, XVI, XVII, and XVIII are control samples for the machines with the lights off.

Table II

Sturtevant Run
E. coli 5% dilution of 23 hour culture
Three jacketed cold quartz Hanovia lights used
Odd numbered tubes before the light
Even numbered tubes after the light
Atomizer on 2:10, on throughout the run

Tube No.	Time	Lights	Relative Humidity	Log. Count	Actual Count	Kill
I	2:39-44	on	36.0%	3.6426	4391	81%
II				2.9224	836	
III	2:45-50	on	36.0%	3.6016	3995	84%
IV				2.7975	627	
V	2:51-56	on	35.0%	3.5479	3531	83%
VI				2.7811	604	
VII	2:57-	on		3.5940	3926	83%
VIII	3:02			2.8133	651	
IX	3:04-09	on	33.0%	3.6693	4670	81%
X				2.9572	906	
XI	3:10-15	on		3.5862	3857	81%
XII				2.8712	743	
XIII	3:16-21	on		3.7297	5366	85%
XIV				2.9102	813	
XV	3:23-28	on	33.0%	3.8959	7868	90%
XVI				2.9102	813	
XVII	3:31-36	off	33.5%	3.7470	5585	
XVIII				3.6171	4141	

During Tubes I-VIII a glass filter (Dustop Filter) two inches thick was placed in the air conditioning system. The average kill with the filter was 82.8%. During Tubes IX-XVI no filter was used. The average kill was 84.3%. Tubes XVII and XVIII were a control on the two machines.

Table III

Sturtevant Run
E. coli 5% dilution of 25½ hour culture
Six ten inch hot cathode Westinghouse lights used
Odd numbered tubes before the light
Even numbered tubes after the light
Atomizer on 2:04, on during the whole run

Tube No.	Time	Lights	Relative Humidity	Log. Count	Actual Count	Kill
I	2:31-36	on	33.0%	3.5857	3853	96.1%
II				2.1790	151	
III	2:38-43	on	32.0%	3.7395	5489	96.5%
IV				2.2833	192	
V	2:44-49	on		3.6826	4815	95.6%
VI				2.3304	214	
VII	2:50-55	on	32.0%	3.6464	4430	95.3%
VIII				2.3203	209	
IX	3:00-05	on	32.5%	3.7760	5970	89.1%
X				2.8133	651	
XI	3:08-13	on	32.5%	3.6464	4430	85.3%
XII				2.8133	651	
XIII	3:24-29	on	32.0%	3.8701	7415	94.4%
XIV				2.6214	418	
XV	3:31-36	on	32.0%	3.6271	4237	88.5%
XVI				2.6883	488	
XVII	3:38-43	off		3.7160	5200	
XVIII				3.8031	6354	

During Tubes I-XII lights were on without a filter, average kill 93%. During Tubes XIII-XVI glass filter (Dustop) two inches thick was placed in the air conditioning duct, average kill 91.4%. Tubes XVII and XVIII are a control for the machines.

Table IV

Deaconess Hospital Run
E. coli 5% dilution 23 hour culture
Four cold quartz Hanovia lights
Atomizer on 1:57 P.M.

Tube No.	Time	Relative Humidity	Lights	Atomizer	Log. Count	Actual Count
I	2:05-10	34%	off	on	4.2166	average
II	2:11-16	31%	off	on	4.1739	14,000
III	2:17-22	29%	off	on	4.1139	
IV	2:23-28	23%	off	on	4.1643	
V	2:29-34	21%	on	on	1.4914	average
VI	2:35-40	21%	on	on	1.2788	14
VII	2:41-46		on	on	1.0000	
VIII	2:47-52	23%	on	on	0.8451	

Tubes I-IV represent the equilibrium reached with the atomizer running and the lights off. The average actual count of four tubes is 14,000.

Tubes V-VIII represent the equilibrium reached with the lights on and the atomizer on. The average actual count is 14. This represents a kill of 99.9%.

Tube No.	Time	Relative Humidity	Lights	Atomizer	Log. Count	Actual Count
				on 2:52-3:02		
IX	3:02-07	19%	on	off	1.4314	27
X	3:08-13		on	off	-	0
XI	3:14-19	20%	on	off	-	0
XII	3:20-25		on	off	-	0
				atomizer on 3:25-35		
XIII	3:35-40	19%	off	off	3.6449	4415
XIV	3:41-46	18%	off	off	2.7463	558
XV	3:47-52		off	off	1.9590	91
XVI	3:53-58		off	off	1.3424	22

Tubes IX-XII represent the removal of organisms with lights on after the atomizer has been running for ten minutes and then shut off.

Tubes XIII-XVI represent the removal of organisms with the lights off after the atomizer has been running for ten minutes and then shut off.

Table V

Cory Hill Hospital Run
E. coli 7.5% dilution 4½ hour culture
Atomizer on 2:27 P.M.
One Hanovia cold quartz light

Tube No.	Time	Relative Humidity	Lights	Atomizer	Log. Count	Actual Count
I	2:35-40	50%	off	on	4.1539	average
II	2:41-46		off	on	4.0518	count
III	2:47-52		off	on	4.1450	13,090
IV	2:53-58		off	on	4.1171	
V	2:59-3:04		on(2:58)	on	1.9682	average
VI	3:05-10		on	on	1.8388	count
VII	3:11-16		on	on	2.1523	81
VIII	3:17-22		on	on	2.0043	

Tubes I-IV represent the equilibrium reached with the atomizer running and the lights off. The average actual count of the four tubes is 13,090. Tubes V-VIII represent the equilibrium reached with the lights on and the atomizer on. The average actual count is 81. This represents a kill of 92.25%.
Atomizer turned on 3:22-37 P.M. One tube IX taken during the build up.

Tube No.	Time	Relative Humidity	Lights	Atomizer	Log. Count	Actual Count
IX	3:31-36		off	on	3.8644	7000
X	3:37-42	44%	on	off	-	0
XI	3:43-48		on	off	-	0
XII	3:49-54		on	off	-	0
XIII	3:55-4:00		on	off	-	0
				on(4:00-15)		
XIV	4:15-20		off	off	2.7640	581
XV	4:21-26		off	off	2.0615	116
XVI	4:27-32		off	off	1.2304	17
XVII	4:33-38		off	off	0.6021	4

Tubes X-XIII represent the removal of organisms with the lights on after the atomizer has been running for fifteen minutes and then shut off. Tubes XIV-XVII represent the removal of organisms with the lights off after the atomizer has been running for fifteen minutes.

Conclusions

1. Wherever people congregate in enclosed spaces micro-organisms characteristic of the respiratory tract are projected into the communal air, to remain there until removed by ventilation, inhalation, irradiation, or germicidal vapors.

2. Large droplets resulting from speaking, coughing, or sneezing, fall to the floor to contaminate dust particles, small droplet nuclei remain suspended in the air wafted about by air currents.

3. Mechanical barriers as cubicles for prevention of cross-infections have limited application in the case of premature or very young infants.

4. Glycol vapors are effective aerial bactericides handicapped by a limited range between 40-60% relative humidity. Data on efficiency in practical applications is much less significant than in the case of irradiation.

5. Dust suppressive measures such as oiled floors and bedding are significant to the extent that contaminated dust is proved to be an etiological factor in respiratory disease.

6. Ultraviolet light irradiation in hospitals has proved to be a useful adjunct to aseptic technique in operating rooms and hospital wards in eliminating cross-infections. In school rooms over a period of years ultraviolet light has prevented the epidemic spread of children's diseases.

7. Elimination of respiratory infections in the general

population is more difficult than with static hospital populations. Unless the protection of adequate sanitary ventilation is afforded in every atmosphere throughout the day and night, a fair determination of the germicidal efficiency of any agent upon human respiratory disease cannot be made.

Bibliography

1. Bigg, E.; Jennings, B.H.; Olson, F.C.W.;American Journal of Public Health Vol. 35,1945 Epidemiologic Observations on the Use of Glycol Vapors for Air Sterilization

2. Bulletin of the U.S. Army Medical Department Vol. 5,1946 Glycol Vapors in Air Disinfection

3. Chapple, C.C.; Aerobiology, American Association for the Advancement of Science Publication No. 17 The Controlled Physical Environment for the Premature and Older Infant

4. Commission on Acute Respiratory Diseases; American Journal of Medical Sciences Vol.209 1945 Atypical Pneumonia

5. Commission on Acute Respiratory Diseases and the Commission on Air-Borne Infections; American Journal of Hygiene Vol. 43, 1946 A Study of the Effect of Oiled Floors and Bedding on the Incidence of Respiratory Disease

6. Del Mundo, F.; McKhann, C.F.; American Journal of Diseases of Children Vol. 61, 1941 Effect of Ultraviolet Irradiation of Air on Incidence of Infections in an Infants' Hospital

7. DuBuy, H.G.; Dunn, J.E.; Brackett, F.S.; Dreessen, W.C.; Neal, P.A.; American Journal of Hygiene Vol. 48, 1948 An Evaluation of Ultraviolet Radiation of Sleeping Quarters as Supplement of Accepted Methods of Disease Control

8. Edward, D.G.; Lancet Vol. 2, 1941 Resistance of Influenza Virus to Drying and Its Demonstration on Dust

9. Greene, D.; Barenberg, L.H.; Greenberg, B.; American Journal of Diseases of Children Vol. 61, 1941 Effect of Irradiation of the Air in a Ward on the Incidence of Infections of the Respiratory Tract

10. Hamburger, M. Jr.; Green, M.J.; Hamburger, V.G.; Journal of Infectious Diseases Vol. 77, 1945 The Problem of the "Dangerous Carrier" of Hemolytic Streptococci

11. Hamburger, M. Jr.; Hurst, V.; Robertson, O.H.; Puck, T.T. Journal of Infectious Diseases Vol. 77, 1945 The Effect of Triethylene Glycol Vapor on Air-Borne Beta Hemolytic Streptococci in Hospital Wards

12. Hamburger, M.; Puck, T.T.; Hamburger, V.G.; Johnson, M.A. Journal of Infectious Diseases Vol. 75, 1944 Studies on the Transmission of Hemolytic Streptococcus Infections

13. Hamburger, M. Jr.; Robertson, O.H.; Puck, T.T.; American Journal of Medical Sciences Vol. 209, 1945 The Present Status of Glycol Vapors in Air Sterilization

14. Harris, T.N.; Stokes, J. Jr.; American Journal of Medical Sciences Vol. 209, 1945 Summary of a Three Year Study of the Clinical Applications of the Disinfection of Air by Glycol Vapors

15. Hart, D.; Aerobiology, American Association for the Advancement of Science Publication No. 17 The Importance of Air-Borne Pathogenic Bacteria in the Operating Room: A Method of Control by Sterilization of the Air with Ultraviolet Radiation

16. Hatch, T.F.; Aerobiology, American Association for the Advancement of Science Publication No. 17 Behavior of Microscopic Particles in the Air and in the Respiratory System

17. Hodes, H.L.; Schwentker, F.F.; Chenoweth, B.M. Jr.; Peck, J.L. Jr.; American Journal of Medical Sciences Vol. 209, 1945 Scarlet Fever as an Air-Borne Infection

18. Jarrett, E.T.; Zelle, M.R.; Hollaender, A.; American Journal of Hygiene Vol. 48, 1948 No. 2 Studies of the Control of Acute Respiratory Diseases among Naval Recruits. II.Limitations of Ultraviolet Irradiation in Reducing Air-Borne Bacteria

19. Jennison, M.W.; Aerobiology, American Association for the Advancement of Science, Publication No. 17 Atomizing of Mouth and Nose Secretions into the Air as Revealed by High-Speed Photography

20. Langmuir, A.D.; Jarrett, E.T.; Hollaender, A.; American Journal of Hygiene Vol. 48, 1948, No. 2 Studies of the Control of Acute Respiratory Diseases Among Naval Recruits III. The Epidemiological Pattern and the Effect of Ultraviolet Irradiation During the Winter of 1946-1947

21. Loosli, C.G.; Robertson, O.H.; American Journal of Medical Sciences Vol. 209, 1945 Recent Studies on The Control of Dust-Borne Bacteria by Treatment of Floors and Bedclothes with Oil

22. Loosli, C.G.; Wise, H.; Lemon, H.M.; Puck, T.T.; Robertson, O.H.; American Journal of Hygiene Vol. 43, 1946 The Oil Treatment of Bedclothes for the Control of Dust-Borne Infection II. The Use of Triton Oil Emulsion (T 13) as a Routine Laundry Procedure

23. Lovelock, J.E.; Nature Vol. 156, 1945 Communication on Aerial Bactericides

24. Lurie, M.B.; American Journal of Medical Sciences Vol. 209, 1945 Experimental Air-Borne Tuberculosis

25. Middleton, S.S.; Gilliland, I.C.; Lancet Vol. 2, 1941 Prevention of Droplet-Borne Infections by Spray A field experiment

26. Puck, T.T.; Journal of Experimental Medicine Vol. 85, 1947 The Mechanism of Aerial Disinfection by Glycols and Other Chemical Agents

27. Puck, T.T.; Journal of Experimental Medicine Vol. 85, 1947 The Mechanism of Aerial Disinfection by Glycols and Other Chemical Agents II. An Analysis of the Factors Governing the Efficiency of Chemical Disinfection of the Air

28. Puck, T.T.; Robertson, O.H.; Wise, H.; Loosli, C.G.; Lemon, H.M.; American Journal of Hygiene Vol. 43, 1946 The Oil Treatment of Bedclothes for the Control of Dust-Borne Infection I. Principles Underlying the Development and Use of a Satisfactory Oil-in-Water Emulsion

29. Ratcliffe, H.L.; Wells, W.F.; Journal of Experimental Medicine Vol. 87, 1948 Tuberculosis of Rabbits Induced by Droplet Nuclei Infection I. Initial Response to Infection

30. Reyniers, J.A.; Aerobiology American Association for the Advancement of Science Publication No. 17 The Control of Cross-Contamination by the Use of Mechanical Barriers I. Principles and Instrumentation for Absolute and Partial Control with Fixed and Circulating Hosts

31. Reyniers, J.A.; Trexler, P.C.; Aerobiology American Association for the Advancement of Science Publication No. 17 The Control of Cross-Contamination by the Use of Mechanical Barriers II. Testing the Efficiency of Mechanical Systems for Controlling Cross-Infection

32. Robertson, O.H.; The Harvey Lectures 1942-1943 Sterilization of Air with Glycol Vapors

33. Robertson, O.H.; Hamburger, M.; Loosli, C.G.; Puck, T.T.; Lemon, H.M.; Wise, H.; Journal of the American Medical Association Vol. 126, No. 16, 1944 A Study of the Nature and Control of Air-Borne Infection in Army Camps

34. Robinson, F.W.; Aerobiology American Association for the Advancement of Science Publication No. 17 Practical Considerations in the Design and Maintenance of Ultraviolet Air Sanitation Equipment

35. Rosebury, T.; The Williams and Wilkins Company, Baltimore, Md. 1947 Microbiological Monographs Official Publication of the Society of American Bacteriologists Experimental Air-Borne Infection

36. Rosebury, T.; Meiklejohn, G.; Kingsland, L.C.; Boldt,M.H. Journal of Experimental Medicine Vol. 85, 1947 Disinfection of Clouds of Meningopneumonitis and Psittacosis Viruses with Triethylene Glycol Vapor

37. Rosenstern, I.; Aerobiology American Association for the Advancement of Science Publication No. 17 Observations on the Control of Respiratory Contagion in the Cradle

38. Sauer, L.W.; Minsk, L.D.; Rosenstern, I.; Journal of the American Medical Association Vol. 118, 1942 Control of Cross-Infections of the Respiratory Tract

39. Thomas, J.C.; Lancet Vol. 2, 1941 Reduction of Dust-Borne Bacteria by Oiling Floors

40. Van den Ende, M.; Andrewes, C.H.; Aerobiology American Association for the Advancement of Science Publication No. 17 Recent Experiences in England with Special Reference to the Importance of Dust

41. Van den Ende, M.; Thomas, J.C.; Lancet Vol. 2, 1941 Treatment of Bedclothes with Dust-Laying Oils

42. Wells, M.W.; Journal of the American Medical Association Vol. 129, 1945 Ventilation in the Spread of Chickenpox and Measles within School Rooms

43. Wells, W.F.; Journal of Bacteriology Vol. 46 No. 6, 1943 Bacteriologic Procedures in Sanitary Air Analysis

44. Wells, W.F.; American Journal of Hygiene Vol. 47, No.1 1948 On the Mechanics of Droplet Nuclei Infection I. Apparatus for the Quantitative Study of Droplet Nuclei Infection of Animals

45. Wells, W.F.; Scientific Monthly Vol. LX May, 1945 Sanitary Ventilation by Radiant Disinfection

46. Wells, W.F.; Journal of the Franklin Institute Vol. 229 No. 3, 1940 Bactericidal Irradiation of the Air

47. Wells, W.F.; Archives of Physical Therapy Vol. XXIII March, 1942 Radiant Disinfection of the Air

48. Wells, W.F.; Industrial Medicine (periodical) Vol. 10 No. 7, 1941 Infection, Disinfection, and Air Conditioning

49. Wells, W.F.; Henle, W.; Proceedings of the Society for Experimental Biology and Medicine, Vol. 48, 1941 Experimental Air-Borne Disease. Quantitative Inoculation by Inhalation of Influenza Virus

50. Wells, W.F.; Ratcliffe, H.R.; Crumb, C.; American Journal of Hygiene Vol. 47 No. 1, 1948 On the Mechanics of Droplet Nuclei Infection II Quantitative Experimental Air-Borne Tuberculosis in Rabbits

51. Wells, W.F.; Riley, E.C.;Journal of Industrial Hygiene and Toxicology Vol. 19, 1937 An Investigation of the Bacterial Contamination of the Air of Textile Mills with Special Reference to the Influence of Artificial Humidification

52. Wells, W.F.; Wells, M.W.; American Journal of Public Health Vol. 28, No. 3, 1938 Measurement of Sanitary Ventilation

53. Wells, W.F.; Wells, M.W.; Journal of the American Medical Association Vol. 107, 1936 Air-Borne Infection

54. Wells, W.F.; Wells, M.W.; Wilder, T.S.; American Journal of Hygiene Vol. 35 No.1, 1942 The Environmental Control of Epidemic Contagion

55. Wells, W.F.; Winslow, C.-E.A.; Robertson, E.C.; American Journal of Public Health Vol. 36, No. 4, 1946 Bacteriologic Procedures in the Evaluation of Methods for Control of Air-Borne Infection

56. Wheeler, S.M.; Jones, T.D.; American Journal of Medical Sciences Vol. 209, 1945 Factors in the Control of the Spread of Acute Respiratory Infections with Reference to Streptococcal Illness and Acute Rheumatic Fever

57. Willmon, T.L.; Hollaender, A.; Langmuir, A.D.; American Journal of Hygiene Vol. 48, No.2, 1948 Studies of the Control of Acute Respiratory Diseases Among Naval Recruits I. A Review of a Four-Year Experience with Ultraviolet Irradiation and Dust Suppressive Measures

58. Wise, H.; Puck, T.T.; Science Vol. 105, 1947 Saturation Concentrations of Triethylene Glycol Vapor at Various Relative Humidities and Temperatures

Abstract

Microorganisms may be present in the air in the form of dust, droplets, or droplet nuclei. They are projected into the air by coughing, sneezing, or talking. Large particles called droplets fall to the ground and upon dessication serve to contaminate dust. The majority of particles evaporate before falling the height of a man: their nuclear residues called droplet nuclei float about on air currents until removed by natural ventilation, inhalation, irradiation, or germicidal vapors.

Experimental evidence seems to indicate that the minute droplet nuclei because of their small size are potentially a greater hygienic hazard than the larger dust and droplet particles. Size determines the place of deposition of particles along the respiratory tract, particles larger than five microns are removed in the upper part, smaller particles reach the alveoli. This has been substantiated in animal experiments with tubercle bacilli.

Epidemiological studies seem to indicate that many respiratory infections such as, mumps, measles, chickenpox, tuberculosis, and atypical pneumonia are air-borne. Moreover, experimentally animals have been infected by inhalation of a great variety of organisms, influenza A virus, pneumococcus Type I, M. tuberculosis, M. mallei, M. pseudomallei, B. suis, P. tularensis, to mention a few.

Dust has been implicated by some observors in hemolytic streptococcus infections. A number of organisms have been islolated from dust. But because of the large size of dust particles it is questionable whether they can cause deep pulmonary damage.

The various methods which have been used in combating pathogens in the air fall into four general classifications; physical barriers, aerosols, oil treatment of floors and bedding, and ultraviolet light irradiation.

Physical barriers have been used as a means of preventing cross-infections in premature and young infants' wards by means of enclosures or cubicles. The Reyniers cubicle and the Chapple incubator for premature infants are examples based on the principle of an individual air supply for each cubicle. Both have successfully reduced cross-infections under practical conditions of use.

The value of masks as an efficient barrier for droplets and droplet nuclei is questionable.

Aërosols are germicides in vapor form. A number of substances have been found to be satisfactory air germicides yet are not suitable for practical use because of excessive corrosive properties, odor, potential toxicity, or high cost. The glycols have satisfactorily met these criteria. Propylene and triethylene glycol have been used as air bactericides with success. Of the two, triethylene

glycol is one hundred times more effective in air. The efficiency of the glycols is associated with relative humidity. Their maximum efficiency is reached at 40 to 60% relative humidity. As the relative humidity deviates from this range, bactericidal efficiency rapidly falls. In practical application in a children's hospital, the incidence of respiratory infections was markedly lower in wards containing glycol vapor than in control wards.

Treatment of floors and bedding with oil has received considerable attention, especially in view of the fact that glycol vapors and ultraviolet lights are limited in action against dust-borne bacteria. Oiling of floors has reduced experimentally by 80% the number of organisms raised into the air by sweeping. Oiling of bedding has reduced the number of organisms liberated during bedmaking by 99%.

Some observors feel that hemolytic streptococci in the air in hospital wards result from activity such as bedmaking and sweeping. The control of air-borne streptococci in hospital wards may simply be a matter of oiling floors and bedding.

Oiling of bedding and floors in a practical experiment did not, however, reduce the incidence of acute respiratory disease.

Ultraviolet light irradiation has been utilized in numerous practical applications. In railroad cars, as a part

of the air-conditioning system, lights have been used to irradiate circulating air.

In operating rooms, direct beams of ultraviolet light focussed upon the operating room table have reduced post-operative infections.

In children's hospitals and infants' wards barriers of light have reduced cross-infections.

In classrooms, mumps, measles, and chickenpox epidemics have been aborted with irradiation.

One observor has protected resistant and non-resistant rabbits from infection with tuberculosis by irradiation and suggests irradiation for the control of human tuberculosis.

In test runs with E. coli on ultraviolet lights in the air-conditioning system of a model railroad car, three thirty inch Westinghouse lights showed a 85.3% kill; three jacketed Hanovia lights had a 84.3% kill, six ten inch hot cathode Westinghouse lights showed a 91.4% kill.

In experiments at the Deaconess Hospital operating room four quartz Hanovia lights produced a 99.9% kill with the test organism, and at the Cory Hill Hospital one large quartz light produced a 99.25% kill.

The growing concept of air-borne infection has resulted in a prolific output of articles on sanitary ventilation. Ultraviolet light irradiation seems the most practical method of diluting pathogenic organisms in enclosed atmospheres

wherever people assemble. Physical barriers for large numbers of people are obviously infeasible, the glycols are limited in application to a short relative humidity range. Ultraviolet lights however are most efficient at low humidities. Consequently, the low humidity of heated interiors during the winter months is particularly suited for ultraviolet irradiation.

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